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WIND AND TURBULENCE INSTRUMENTATION FOR
AIR POLLUTION STUDIES

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Air Pollution Studies

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It should be made clear at the outset that my approach to the subject matter under discussion is not as an instrument technician. I am not a so-called "instrument man" as many of you well know, but operate according to the perhaps naive assumption, which is certainly not original, that one doesn't have to know how a watch runs to tell the time. This position is not at great variance from that of many customers of commercial wind instrumentation. We are primarily interested in wind movements, not in wind instruments as such. Therefore, it is strictly as a customer of equipment manufactured to detect and depict those wind movements that I am speaking today. If the affliction of chronic eye strain from hours of reading and tabulating miles of wind-record charts is an additional criterion of my suitability for opening this discussion, then I am also well qualified.

The observation is frequently made by users of wind instruments, particularly for the study of turbulence, that much effort goes into the sensing instrumentation and little energy and thought into the main job of conveniently digesting or even depicting the data. The technicians who develop wind instruments or sensing devices apparently don't actually use them. If they were required to sit hour after hour, day after day, reducing records of strip charts, 35-mm. film, etc. into forms suitable for subsequent quantitative analysis then perhaps, as Cramer has pointed out, they would " . . . realize the necessity for utilizing the data-handling techniques

that have been in common use in other fields for many years."

Another distressing point is that not all of the instrument makers can tell you exactly what their sensors see and what they do not see, nor how completely or accurately the potential intelligence is displayed in the record. Particularly with regard to wind fluctuation data, this becomes an added problem to the analyst. The answers will have to be dug out by means of time-delaying, expensive tests and calibrations or, if one is lucky, by finding some other means to provide the needed information.

Therefore, it is not inappropriate that a "user" or "customer" of wind equipment for air pollution studies should lead off this morning's discussions. After all, no matter how well a watch may be designed nor how meticulous or precise its manufacture, the proof is in the time it keeps and how easy it is to read. The instrument designer, on the other hand, can hardly be expected to accept all of the blame for our complaints about the tools with which we have to work, if our requirements are not spelled out in terms as precise as our knowledge of our needs permits us to be .

It is this latter problem with which we are primarily concerned in this clinic. I should like to quote directly from a manufacturer's letter I received recently which strikes at the very heart of the issue " . . . the meteorological profession must make an endeavor to stimulate commercial interests in its problems by providing a more uniform concept of the requirements for this science. Without this basis for wider application, there can be no advantage taken of production techniques and other factors which lend themselves toward instrumentation available at a lower cost." I am confident that this opinion must be widely held throughout the wind equipment industry.

Therefore, if we can reach reasonable agreement on a delineation of wind measurement requirements in each of the facets of air pollution studies or surveys, a significant accomplishment will be achieved. During the past

few months engineers or representatives of three wind-instrument manufacturing companies have visited our office, and I know some of you have been similarly visited, to discuss this matter of current and anticipated instrumental requirements. If this can be taken as a "straw-in-the-wind," indicating that new models or completely new instruments are being planned, then perhaps the present time is most appropriate for this instruments clinic.

The overwhelming importance of air movements in the transport and dilution or diffusion of atmospheric contaminants, whose description, if not prediction, is the ultimate objective of virtually all air pollution studies today, hardly needs to be impressed upon this group. When speaking of air movements, we generally speak of three quantities: mean wind speed, mean wind direction, and turbulence; but as each of these quantities exists only by definition, further explanation is always required to effect a comprehensive quantitative or analytical exposition of air movement manifestations. But even when speaking in qualitative terms, wind direction, speed, and turbulence do picture to us certain physical phenomena which have similar effects on the transport and diffusion of air pollution. We know that if pollution is injected into an air stream, the mean direction of the flow indicates the mean direction the pollution will be carried. The mean wind speed indicates, on the average, the volume of air per unit time into which the effluent will be injected and diluted. Turbulence is recognized as the primary diffusing mechanism in the atmosphere, as a steady wind is capable of effective dilution of air pollution in only one dimension.

However, as you all recognize, to give the above phenomena practical meaning, we must define what we are talking about in terms capable of translation into analytical formulations or working equations which are subject to the test of experimental verifications by exact and quantitative measurement. The concept that the "instantaneous" wind is made up of a mean and an

"eddy" component is convenient in this respect. In practice, we do not measure the instantaneous wind velocity, but we often use a quantity averaged over appreciable time intervals for the "instantaneous" value. The minimum averaging time is set by the response time of our sensing and recording or indicating gear. In order to keep the oral notation clear, the element of time over which we choose to select the value of our variable in lieu of an "instantaneous" value, will be called the "averaging time," while the time over which the mean is taken will be called the "sampling time." I suggest that we test our ability to agree or compromise today by reaching an agreement on these or some other notations. Such agreement will be a great help in communication, as these terms are used in many ways. I have no strong brief for their use other than they were generally adopted at the Oxford symposium last fall and thus an international precedent was set.

Wind data from both standard and specialized instruments are reduced, analyzed, or utilized in a large variety of fashions, and because the basic data required for one purpose are often the same as for another or several other studies, the requirements fall roughly into three general categories. It will be much simpler then to talk about the instrumental requirements for these particular classes of studies, rather than about the needs entailed in each individual application of wind data in air pollution studies.

The three categories of air pollution studies which can be set up in order to classify or group similar wind data requirements are:

- I. Climatological surveys
- II. Operational or "synoptic" activities
- III. Research studies

It is appreciated that the instrumental requirements in each of these categories are not absolutely mutually exclusive. Especially between categories II and III there is a large gray area, as many research studies

are carried on in direct support of, if not actually integrated within, operational activities, and some climatological surveys might well be classified within the realm of research. Nevertheless, the differences in the nature of wind data normally utilized in each of these activities are sufficient to make them a reasonable basis for discussion.

I. Climatological surveys

Climatological surveys, for the most part, entail tabulation and analysis of either average or nearly instantaneous wind quantities. By the latter I mean observations made, say, once an hour rather than hourly means determined from continuous records. The aim of most of these surveys is to describe quantitatively the climatological features of the wind flow at one or more specific locations, or spatial and temporal patterns over a region of interest, and their relation to air pollution travel or dispersion potential. These descriptions are expressed in innumerable ways, such as frequency distribution tabulations or graphical displays, wind roses, stream line analysis, etc., the details of which are not particularly relevant at this time. However, with few exceptions, these surveys do not include analyses of statistical properties of the fluctuations in wind speed or direction as such. This omission is probably due to the fact that statistical data on wind fluctuations are not readily available; and even if such information could be extracted from available historical records, it would be laborious and expensive to obtain. Nor am I aware of any great feeling in the meteorological profession that such detailed statistics would be of sufficient usefulness in a general climatological survey to justify the expense.

From the point of view of the wind sensor characteristics required to provide the data used in climatological surveys or studies, the situation is a bit anomalous. On the one hand, sensors of extremely fast response are not

required; in fact, we might even say they are undesirable. Here we do not want records which, in this context, are confused by a lot of "noise." If we are dealing with records of hourly observations we would like to have them more representative of a moderately long-period motion than of a very short-period fluctuation. Similarly, if we are extracting hourly mean speeds and directions from a continuous record by eye, it does help if the record is comparatively uncluttered. There is no sound physical basis of which I am aware for making a categorical statement of the averaging time which should be used in climatological surveys. Experience must be the basis of any standards, together with educated guesswork. I'm sure we all agree on the factors which enter into the picture: the temporal and spatial scales of the problem, nature of the underlying surface, and height above the ground at which the measurements are made primarily. For most purposes a minimum response time to wind fluctuations of several seconds is fast enough to do the job. As you know, there are many excellent instruments commercially available which meet this requirement.

On the other hand, it would be desirable to have wind speed sensors with low-starting speeds, since most of our community air pollution episodes occur during periods of calm or with very light winds. Here too, I believe our needs are met as well as we can expect with commercial instruments, considering also the very important matters of costs and durability. These last items must be balanced against the detail required in the record as well as the form of the final record desired. Sensitive instruments with starting speeds less than 1 mph are relatively expensive, but I understand that the Instrumental Engineering Division of the Weather Bureau has modified a standard WB Fl420 cup system with a photo-cell-chopper pickup that gives less than 1 mph starting speed and should be cheaper if put in routine production. Totalizing anemometers with starting speeds of on the order of 2 mph are

inexpensive and give reasonably good performance in the field for fairly long periods with a minimum of maintenance. If one can be satisfied with a starting speed of the order of 3 mph, then very durable wind instruments are available at a moderate cost whose records are not unreasonably noisy for the determination of average values of speed or direction by eye inspection.

Useful climatological statistics on the general level of turbulence can be extracted from continuous records from conventional wind equipment. The Brookhaven gustiness classification system, which does not require a detailed analysis of the wind trace, is an excellent example of the use of standard equipment. Also instruments have been designed, and at least one is commercially available, specifically for the purpose of giving data on gustiness. The "bridled cup accelerometer," first developed many years ago by Gill and Hewson, is one important example. I understand this instrument has recently been improved in design and equipped with a potentiometer so that it can indicate both wind speed and rate of change of wind speed. A counting device is on the market which, by providing an electrical contact for each 100 degrees of movement in one direction, gives an integrated measure of turbulence. While I do not believe that an integrated record of turbulence such as these instruments provide, tells us all we need to know about turbulence, the simplicity of their operation and record should make them attractive for the purpose of obtaining valuable climatological statistics on turbulence regimes.

The problem of recording wind direction without ambiguity has been solved for some time; unfortunately not all manufacturers have adopted wind direction sensing and recording systems with this advantage, however. In this connection, I might call your attention to the fact that a system has been recently reported by Maynard Smith of Brookhaven National Laboratory which utilizes relatively simple components and operates with standard

indicators and recorders. Its durability is said to be comparable to that of existing instrumentation.

However, the question should be raised at this time whether we really need continuous strip chart records of wind speed and direction for climatological purposes. By demanding continuous records, may we not be in a somewhat position analogous to that of a meteorologist who will not have anything to do with a weather map he does not plot and analyze himself? At least one automatic recording device is on the market which takes the input from a standard cup anemometer and wind vane and prints out wind direction and an integrated speed on an adding machine, electric typewriter, tape punch, card punch, or combination, according to the descriptive brochure. I have not had any experience with this device, but perhaps some of you have and could enlighten us further. Also, an interesting system has been developed at Hanford which presents the true resultant wind vector for periods of integration of 5, 15, 30, or 60 minutes. Initial costs will play an important role in the extensive utilization of these equipments for climatological studies. Conversations I have had with local groups or agencies, potential customers for such devices, indicate that a price of about \$1500 would not be considered excessive.

To summarize the instrumental situation for air pollution studies in the climatological survey category, it is not immediately apparent that any innovations or techniques are particularly needed at this time. Rough and ready indications of turbulence levels can and are being obtained from continuous records of standard and specialized instruments. However, if the fashion changes such that it is believed necessary to include routinely detailed statistics on wind fluctuations, then new methods for records reduction will be highly desirable.

II. Operational or "synoptic" activities

For the probable majority of meteorologists working in the air pollution or atmospheric diffusion field, operational activities represent the "bread-and-butter" area. The problems vary from site to site, but primarily meteorological monitoring of the diffusion and dispersion of effluents from industrial or atomic processes is involved. Fortunately, more and more meteorological advice is being sought by engineers in the planning stages of projects. It is in connection with this planning aspect that research activities frequently impinge on the operational aspects of diffusion meteorology.

For strictly operational activities, most groups have their own techniques and procedures already worked out to suit the nature and scale of their specific problems. Hence, it must be assumed that for present routine operations requirements, the instrumental needs are largely satisfied. However, there is no group of which I am aware that feels it has all the answers. Improvements in techniques, working formulae, and instrumentation are constantly advancing. New problems are encountered almost every day; and as we all deal with the same atmosphere, rarely is an advance in knowledge at one site inapplicable in one way or another to all sites or problem areas.

But to get down to the instrumentation aspects, I should like to point out that operational activities frequently involve one or more networks of wind stations. We seldom talk about only one instrument or set of instruments located at some central headquarters or field station. The scales of the problems encountered may range from local to distances over which homogeneous turbulence cannot be assumed, or over which the effects of meso-scale atmospheric processes cannot be neglected. It will be assumed, therefore, that the data required from any one wind instrument will also be required, or would be desirable, from all similar instruments. Techniques or systems for the telemetering of data to a central location will not be discussed.

Common to all of these studies is the need for the definition and determination of mean wind speed and direction. Utilization of additional wind information depends on the diffusion formulation in use or being tested. Sutton's formulation, for example, requires implicit knowledge of the vertical gradient of the mean wind. Knowledge of the variance of the fluctuating velocity components is also required for the direct evaluation of his virtual diffusion coefficients. In practice, however, these coefficients are rarely evaluated other than indirectly, without actual recourse to measured values of the variance of the velocity components.

Instrumental requirements for the measurement of mean wind speed and direction for studies in the operations category are not necessarily more demanding than for climatological studies. The distances or times of travel involved are such that conventional anemometry can normally be utilized.

Although there has been some quantitative dabbling with wind fluctuations for some time, recent work both in this country and abroad is demanding closer attention in this direction than ever before. Cramer, Record, and Vaughn, for example, have stated that from their experiments it appears that " . . . the standard deviation of azimuth wind direction shows promise of serving as a universal diffusion indicator," and the recent work at Porton by Hay and Pasquill seems to substantiate this conclusion. The notion of using measurements of the wind fluctuations directly rather than derived coefficients in working formulae is attractive and physically more appealing than indirect measures of the eddy motions by temperature or wind gradients. We cannot expect, however, the variance or standard deviation of a wind fluctuation in itself to tell us all we need to know of the effects of the fluctuation on dispersion. The variance alone does not necessarily give us any information about the spectral distribution of the turbulent energy. This must be determined directly by means of a spectrum computation, or be

indirectly inferred by means of radiation or lapse-rate measurements.

Now we can argue at great length about the applicability of working formula developed from the rather limited experiments mentioned. However, I do not think this argument is particularly appropriate in this clinic. It has been demonstrated that quantitative wind-fluctuation data can be used successfully in simplified working diffusion formulations. These formulations will be quite useful for application to a large number of practical problems for which the conditions of the experiments fit reasonably well. At least I am sure that many of us will try to use them in the future over fairly regular or homogeneous terrain and at distances up to at least a few kilometers.

For the prediction of, say, ground level concentration of pollution from elevated or surface sources over a distance of many kilometers, we have very little to go on to tell us what kind of wind data are or will ultimately be required. I am thinking now of the kinds of problems met in community air pollution studies. In discussing his mathematical model of the diffusion of air pollution over the Los Angeles area, Frenkiel has stated that the main difficulty in applying the model was that while valuable data on hourly flow patterns were available, data on the turbulent fluctuations of the wind were not sufficient. The clear implication is then that data on the variance of the wind direction fluctuations, or speed fluctuations, are needed for the multiple-source urban problem.

However, our own experience so far in connection with the detailed air pollution study for the city of Nashville does not point to this conclusion. A reasonable degree of success is indicated in delineating patterns of ground concentrations of SO_2 , using a very simple model whose parameters are evaluated in terms of what amounts to a K theory. Wind fluctuations are used only qualitatively to classify turbulence regimes, similar to the gustiness classification system developed at Brookhaven, although right now we do

not use as many categories. I believe we are using the best air quality measurement techniques available, which are at the same time practical for routine, day-to-day, month-to-month field operations for a large number of samples. Nevertheless, I suspect that we can predict the ground level distribution of this pollutant, even with our crude model, about as accurately as it can be measured. Considering also the complicated problem involved in a source inventory for an entire city, and all the inherent inaccuracies, it is my feeling that to bring more sophistication into the model by introducing the wind fluctuations explicitly would just be "gilding the lily."

Little is known at the present time of the importance of local measurements of wind fluctuations in problems involving the long-range travel of effluent from a single source. Let us hope that the experiments to be conducted at Hanford this summer are successful in giving us more information on that point.

But let us return to those studies in which wind fluctuation statistics are needed or desirable in a quantitative fashion. The first question is whether or not instruments or measuring techniques are available to do the kind of job we really want. Let us put aside for the moment the question of whether we intend to use the fluctuations of, say, wind direction, or whether we intend to use the fluctuations of one or more components of wind velocity. If we think of one of the important statistics of wind fluctuation, the variance, from the point of view of the spectrum of atmospheric turbulence, we can think of that variance as representing the sum of the contributions between two different time scales, or space scales, if you allow the Taylor transformation. The range of scales represented by the variance depends, of course, upon the averaging and sampling times used to determine the variance, as well as upon the existent spectral distribution of those fluctuations in the atmosphere. In order to discuss an observed distribution of an air

pollutant in terms of the variance of a wind fluctuation, the pollution distribution must have been sensibly governed or determined by those motions represented in the computed variance. In other words, if the computed variance represents the energy of only very small eddies, say, with periods between 1 and 2 seconds, it can hardly be expected to explain the distribution of an air pollutant after an hour or two of travel.

The question of proper averaging time, as well as proper sampling time, for every type of diffusion problem and for any meteorological situation is far from solved. Nor will this question be resolved until more work has been done on the third category of the problems, i.e., research concerned with the structure of turbulent flow. However, it is in terms of the averaging time especially that the question of proper instrumentation must be looked at in this clinic. Proper sampling time is primarily a meteorological question and not one of instrumentation. Selection of a proper sampling time depends upon several factors in addition to the existent turbulent spectrum. Among these are: time of emission of the effluent, if it is not a continuous emission; the geometry of the problem, that is, for example, whether the source is at the surface or aloft; and the position of the receptor. Other factors include: the time of pollutant travel to the receptor, the time over which the pollutant is sampled at the receptor, and the ambient stability conditions. The present experience seems to indicate that for times of pollutant travel greater than about one minute the wind sampling time should not be less than 10 minutes in stable conditions and 30 minutes under unstable conditions.

The matter of proper averaging time, aside from the meteorological implications, has a direct bearing upon the response characteristics of instruments now available for the measuring of wind fluctuations. Here again, categorical statements are extremely dangerous to make. We can derive from

those comparatively few studies which have been made of the structure of turbulent flow under various stability conditions, some guesses as to the minimum instrumental response times required. Turbulent theory would lead us to argue at first blush that we may need to be concerned with motions which are in the inertial sub-range of the turbulent spectrum. However, to demand commercial instruments capable of faithful reproduction of motions well in the inertial sub-range, is, I think, asking too much right now considering the uncertain state of our knowledge. We can not guarantee to ourselves nor to the manufacturers that such rapid response and sensitive instrumentation is actually needed to provide the proper answers to the day-to-day practical problems we face in air pollution.

Going back to theoretical considerations, however, I would like to suggest that significant quantitative statistics on wind fluctuations can probably be obtained without highly specialized, laboratory-built equipment. Under conditions of moderate levels of turbulence, in convective situations especially, the response of the sensor and recording equipment is probably sufficiently fast if a faithful reproduction is obtained of those fluctuations whose period is equal to or less than one-half the ratio of the height of observation to the wind speed. That is,

$$T < \frac{Z}{2\bar{u}}$$

Variances based upon such averaging times would then, presumably, cut off at the upper end near the beginning of the inertial sub-range and no sensible energy should be lost. Low-inertia anemometers and vanes are commercially available which apparently can meet this criterion for the wind speeds and heights of observation within the range of real interest in air pollution studies. During stable conditions over smooth terrain instrument response

based on the above criterion may not be satisfactory.

Further experience may well show that the limitation set above is unduly restrictive, particularly for effluent travel of many minutes and over moderately rough terrain. In any case, it is unlikely that averaging times greater than about 5 seconds would be satisfactory.

Whether one wishes to go to averaging times below 1 second or up to 5 seconds for analyzing wind fluctuations, two needs must be satisfied to make the practice fully operational. The first is a commercially available, suitably damped bivane or other type of sensing device which can give vertical fluctuations of the scales of motion to which the fast commercial wind instruments are capable. The second more important item is some kind of a black box into which we can plug the signal from the wind sensors and come out directly with the statistics of those fluctuations printed on a tape or recorded in the form of a strip chart record.

As for the fast, all-weather bivane, the Weather Bureau group at Idaho Falls has designed and tested a prototype whose response characteristics, I understand, are quite similar to one of the fast commercial anemometer systems. The bivane is now on the market at a reasonable price, about \$500. Gerry Gill, at the University of Michigan, seems to be coming along very well with the re-design of his light bivane, originally built at M.I.T., to make it at least an "almost" all-weather bivane. He will undoubtedly say more about this later on. However, unless one intends to use only direction fluctuation statistics in angular measure, the importance of matching bivane and anemometer characteristics should not be overlooked.

To go back to the black box, it is in this area of rapid data reduction and analysis aids that meteorological wind instrumentation needs are the greatest, and it is from this direction that the next real forward stride can come. We can do, and some of us are doing, a great deal to alleviate

the problem of data handling. The data-processing system being developed at M.I.T. is a good example. According to a report by Vaughn, the system will perform four major functions:

- (1) Encoding of analog information from sensing elements in the form of binary numbers.
- (2) Storage of these numbers in a relay memory until they can be placed on perforated paper tape.
- (3) Decoding of the perforated tape.
- (4) Presentation of the data either in the form of sequences printed on an IBM typewriter or as entries on punched cards.

From this point one can then proceed with analysis by machine or hand computation as required. It is said that the system was purposely made sufficiently versatile so that information from slow-response-type instruments can also be accommodated.

As example in our own office, data are printed on an electric typewriter and entered on punched cards by means of a commercial curve reader, but one must still read the original charts by eye.

Both of these systems, and especially the one under development at M.I.T., are better than anything available to meteorologists a few years ago. Except for the study of the structure of atmospheric turbulence, which I would classify as research, it does not seem likely that operational requirements data need be kept in permanent or semipermanent form, as on punched cards or as a continuous trace on a chart. Further, the field or site of operations may be a long way from an electronic computer so that accurate, on-the-spot evaluations can be only qualitative at best.

The ultimate solution must be in the form of the black box previously mentioned. It may not be little, and there may have to be more than one, but it will be in the field, giving forth such information as the running mean

wind direction and speed and the variance or standard deviation of wind fluctuations, either of azimuth and elevation or velocity components.

It is good to report that serious work on such black boxes has begun. Two prototypes that I have seen are in operation, one in this country and one in England, while there are rumors that at least three other groups in this country have them under development. Those I have seen are designed to present the standard deviation of the wind direction fluctuations for selected sampling times by a curve-drawing recorder. One was built by Dr. Grinnell, of the Chemistry Department of Stanford University, and the other by Dr. Pasquill and his group at Porton. Time does not permit giving the details of these systems. I understand Dr. Grinnell gave a talk about his at an A.G.U. meeting in California last month, and a paper by Jones and Pasquill covering their devices has been offered for publication. Therefore, the full stories will be available soon. As far as I am aware, the important differences are that the Porton device presents automatically by electrical filters the basic effects of averaging and displays data embodying three separate sampling times simultaneously and continuously.

More work will have to be done on the black boxes before they can give us all the information we want. As mentioned, they now read out the standard deviation of the wind direction fluctuations in angular measure. It should be easier to get the standard deviation of elevation deflection, with a suitable sensor, as the definition of the mean is far simpler. By proper conversion and combination of anemometer and bivan signals in another black box, it was demonstrated at Brookhaven several years ago that it is feasible to record directly vertical velocities rather than elevation angles, and presumably the same can be done for the transverse and longitudinal velocity components.

The ultimate cost of the black boxes can hardly be speculated at this time. They can cost perhaps several thousands of dollars and still be economical compared to the cost of the same work by hand. They should be priced to compete with a system such as that developed by M.I.T. The convenience of field operations permitted by the portable black box would be worth some extra dollars.

Two other areas of study in which wind measurements are a problem should also be mentioned. The first is in the delineation of pollution trajectories, particularly during light winds and over irregular terrain. Fixed wind-measuring systems would not appear to ever be the ultimate solution. Visual tracking of smoke plumes, or smoke plume photography, has been found useful, but there are obvious limitations to these techniques. The most promising technique now on the horizon seems to be tracking constant-level balloons by radar. The Weather Bureau is now experimenting along this line, using metallic-coated Mylar "tetroons." Since these tests are now in progress we shall have to await the outcome to judge the feasibility of such a method for determining trajectories.

The second problem is in obtaining wind data in the vertical when a tower is not available or is not as high as one would wish. Some kind of a tethered system might be satisfactory in some cases. You will recall that Jones and Butler described a successful and operational system recently in the Quarterly Journal of the Royal Meteorological Society. However, a system which can be utilized in areas where air-space congestion is a problem has yet to be devised.

III. Research Studies

This last category is included only for the sake of completeness. The instrument requirements here are broadly those involved in micrometeorological investigations and experimental studies of the structure of turbulent flow.

Experience shows us that these fields are not profitable for commercial instrument makers except on the basis of developmental contracts. Because the instruments are highly specialized and because each group has usually developed its own favorite techniques and instrumental equipments, there is little uniformity.

For the study of the structure of turbulent flow, it appears that adequate sensing techniques are available for the delineation of the local time features of the flow. Hot wire anemometry has apparently been developed into a fine art, especially for meteorological purposes, by Priestley's group in Australia. Perhaps Mr. Swinbank will comment further on this. Sonic anemometry appears to hold promise. Most of you are undoubtedly familiar with Suomi's 1-meter sonic. At the University of Washington, Businger is now starting construction of a new one which will measure the phase shift between transmitted and received sound over a known distance rather than the time from the initiation of a sound pulse at one point to its reception at another as is the basic measurement with the Suomi instrument. According to Monin, a sonic with a 6-cm. path length has also been developed in Russia, but I have no details on its design or operation. The U.S. Army Signal Corps also reports to have an acoustical wind and temperature system in the final stages of development.

Here again, however, troubles lie in rapid and convenient techniques of data reduction and analysis. While the need for on-the-spot evaluation may not be as great as in operational activities, the little black box would be extremely useful.

CONCLUSIONS

From this brief and admittedly incomplete survey of the field of wind instrumentation for air pollution studies, the following points appear to stand out:

1. To the extent that we can be satisfied with knowledge of the local time features of air flow, there is no apparent need for the invention or development of new wind sensors at this time.
2. There is an urgent need for an inexpensive and convenient method for the analysis of wind variability, preferably by means of gear which is an integral part of the wind sensing-recording instrumentation. Agreement must first be reached within the meteorological profession, however, upon standard averaging and sampling times which will be generally acceptable.
3. The need for continuous wind records, especially of wind speed, is seriously questioned. Systems capable of providing resultant wind vectors for selected sampling times would appear to be preferable.
4. The demand for a commercial bivane will probably be considerably increased if an inexpensive "variability analyzer" is developed.
5. Wind instrumentation should be capable of giving data on the magnitude of gustiness when that instrumentation is operated for the purpose of collecting climatological information.
6. Suitable techniques for the determination of air trajectories and vertical sampling without the aid of towers have yet to be devised.

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